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Annotated Bibliography on Hypoxia and its Effects on Marine Life, With Emphasis on the Gulf of Mexico

Maurice L. Renaud

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Annotated Bibliography on Hypoxia and its Effects on Marine Life, With Emphasis on the Gulf of Mexico

MAURICE L. RENAUD[1]

ABSTRACT

This bibliography contains 73 annotated references from publications and reports concerning hypoxia, ⩽ 2.0 ppm dissolved oxygen concentration, in the Gulf of Mexico. Instances of hypoxia from similar habitats and the effects of low oxygen levels on marine or estuarine organisms are also included.

INTRODUCTION

Marine and aquatic organisms require various levels of dissolved oxygen to maintain normal growth and activity. Hypoxia, ⩽ 2.0 ppm dissolved oxygen concentration, occurs naturally in several regions of the world and creates a stressful condition for most organisms subjected to it. A variety of environmental variables are associated with the formation of oxygen-depleted water. Freshwater runoff, water column stratification, biological processes, and weather conditions appear to play major roles in hypoxia formation. The extent to which any single factor is involved is unknown.

During the past 10 yr, hypoxia has become a major concern to scientists and commercial fishermen in the Gulf of Mexico. Hypoxic or anoxic conditions have been reported annually in the Gulf of Mexico since 1972. They have been concentrated along the Louisiana coastline between the Mississippi River Delta and Marsh Island, LA. More recently, hypoxia was noted off western Louisiana and the upper Texas coast.

The full effect of hypoxia on the commercial fish and shrimp industries is unknown. Although hypoxia has not been directly linked to temporary changes in migratory patterns or in the decline of annual shrimp catch, its presence during portions of a shrimp's life cycle implicate it as a possible source of variation in annual yields.

This paper contains 73 annotated references that document the occurrence of hypoxia in the Gulf of Mexico and similar coastal habitats, or address the effects of oxygen depletion on marine life. References were obtained through a computer survey of Biological Abstracts, Aquatic Sciences and Fisheries Abstracts, National Technical Information Service, and library research. All articles in this bibliography were reviewed by the author. Users are encouraged to alert the author of any omissions so that addenda can be produced.

ACKNOWLEDGMENTS

I would like to thank Beatrice Richardson for typing the manuscript; the librarian, Pat Torrefranca, for the acquisition of several articles not present in our library; and Lorna Kent for the computer literature survey.

[1]Southeast Fisheries Center Galveston Laboratory, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77550.

ANNOTATED BIBLIOGRAPHY

Adams, J. K.

1983. Oxygen depletion on the OCS: Session summary. Proc. 3rd Annu. Gulf Mex. Inf. Transfer Meeting, p. 182-183. U.S. Dep. Inter., Minerals and Management Serv., New Orleans, LA.

Summarization topics include 1) the occurrence of hypoxia in the Gulf of Mexico, 2) factors influencing hypoxia, 3) characterization of Mississippi River water, 4) sources of oxygen-demanding material, 5) areal extent of hypoxic bottom water, 6) research needs concerning the prediction of hypoxia, and 7) understanding the processes in the ecosystem controlling hypoxia.

Alderdice, D. F., W. P. Wickett, and J. R. Brett.

1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Board Can. 15:229-249.

Discusses the effect of hypoxic conditions on the embryological development, i.e., fertilization through hatching, of the salmon egg. Mortality and hatching success are noted.

Barrett, B. B., J. W. Tarver, W. R. Latapie, J. F. Pollard, W. R. Mock, G. B. Adkins, W. J. Gaidry, C. J. White, and J. S. Mathis.

1971. Cooperative Gulf of Mexico estuarine inventory and study, Louisiana. Phase II, Hydrology, p. 9-130. Louisiana Wild Life and Fisheries Commission, New Orleans.

Dissolved oxygen concentration, turbidity, nitrates, nitrites, inorganic and total phosphates were measured at 82 stations in Louisiana estuaries from Sabine Lake to the Pearl River, from April 1968 to March 1969. Seasonal and geographic variation of data are discussed.

Bedinger, C. A., R. E. Childers, J. W. Cooper, K. T. Kimball, and A. Kwok.

1981. Pollution fate and effect studies. *In* C. A. Bedinger (editor), Ecological investigations of petroleum production platforms in the central Gulf of Mexico, Vol. 1, part 1, 53

p. Final report to the Bureau of Land Management, New Orleans, LA. Contract No. AS551-CT8-17.

Review of the geology and physical oceanography on the outer continental shelf of the Gulf of Mexico, i.e., advective processes, Louisiana shelf circulation, dissolved oxygen levels, water column stratification, photosynthesis, and estimates of petroleum hydrocarbons in the Mississippi River discharge. An examination of hypoxic occurrences is included. Cause and effect relationships are discussed.

Boesch, D. F.
1983. Implications of oxygen depletion on the continental shelf of the northern Gulf of Mexico. Coastal Ocean Pollut. Assess. News 2:25-28.

A concise review of documented hypoxia in the Gulf of Mexico. The severity, potential causes, and consequences of hypoxia are evaluated.

Brongersma-Sanders, M.
1957. Mass mortality in the sea. *In* J. W. Hedgpeth (editor), Treatise on marine ecology and paleoecology. Vol. I. Ecology, p. 941-1010. Geol. Soc. Am. Mem. 67.

Classifies mass mortality in the sea into general categories, i.e., catastrophe, sudden changes in environmental parameters (temperature, dissolved oxygen concentration, salinity, and currents), phytoplankton blooms, etc. A catalog of worldwide mass mortalities in the sea is presented. Biological and physical processes resulting in the depletion of oxygen on the ocean floor are discussed.

Bulloch, D. K.
1976. Ocean kill in the New York Bight: summer 1976. Underwater Nat. 10:4-12.

Presents the chronological reporting of the fish and invertebrate kill. Information was collected from commercial and sport fishermen and scuba divers. A low dissolved oxygen concentration in the bottom water of the New York Bight was identified as the cause of the mortalities. Possible sources of the low oxygen levels are discussed.

Burton, D. T., L. B. Richardson, and C. J. Moore.
1980. Effect of oxygen reduction rate and constant low dissolved oxygen concentrations on two estuarine fish. Trans. Am. Fish. Soc. 109:552-557.

Atlantic menhaden, *Brevoortia tyrannus*, and spot, *Leiostomus xanthurus*, were examined. Relationships between the mean lethal concentration of oxygen and the rate of reduction of dissolved oxygen that induces a fish kill were determined.

Carpenter, J. H., and D. G. Cargo.
1957. Oxygen requirement and mortality of the blue crab in the Chesapeake Bay. Chesapeake Bay Inst., Johns Hopkins Univ., Tech. Rep. 13, 22 p.

Discusses blue crab mortalities in Chesapeake Bay from 1951 to 1953. Dissolved oxygen concentration and water circulation in the Bay are examined. Resistance times to varying degrees of hypoxic water are calculated. Wind direction and speed, tidal velocity, and air and water temperatures are considered.

Childress, J. J.
1968. Oxygen minimum layer: vertical distribution and respiration of the mysid *Gnathophausia ingens*. Science (Wash., DC) 160:1242-1243.

The oxygen consumption rate of *G. ingens* was measured in water with a dissolved oxygen concentration ranging from 0.0 to 0.3 ppm. The ability of *G. ingens* to function under anerobic conditions, and the production and maintenance of the oxygen minimum layer in the deep sea are discussed.

Connell, C. H., and J. B. Cross.
1950. Mass mortality of fish associated with the protozoan *Gonyaulax* in the Gulf of Mexico. Science (Wash., DC) 112:359-363.

Reports on temporal fluctuations of oxygen levels in Offatts Bayou with respect to *Gonyaulax* sp. activity and fish kills.

Conseil Permanent International Pour l'Exploration de la Mer.
1936. Bulletin hydrographique pour l'année 1935 (Series B1), 105 p.

Provides oxygen, phosphate, and nitrate profiles at numerous locations in the Gulf of Mexico during 1935.

Davis, G. E., J. Foster, C. E. Warren, and P. Duodoroff.
1963. The influence of oxygen concentration on the swimming performance of juvenile Pacific salmon at various temperatures. Trans. Am. Fish. Soc. 92:111-124.

Experimental evidence suggests that minor changes in dissolved oxygen concentration severely affects the swimming behavior of the chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon. This could impact food gathering, predation, and escape behavior, i.e., survival of fish in the wild. May be applicable to Gulf species as well.

Deubler, E. E., Jr., and G. S. Posner.
1963. Response of postlarval flounders, *Paralichthys lethostigma*, to water of low oxygen concentrations. Copeia 1963:312-317.

Examines behavior of postlarval flounders in oxygen-depleted water.

Drake, T.

1982. Oxygen depletion as influenced by the Mississippi River outflow. Proc. 3rd Annu. Gulf Mex. Inf. Transfer Meeting, p. 183-184. U.S. Dep. Inter., Minerals and Management Serv., New Orleans, LA.

Characterizes oxygenation and reoxygenation in the lower Mississippi River. Examines historical and future trends and describes the effects of dredging in the river. Discusses future dredging planned by the Corps of Engineers at Southwest Pass, LA, and the need for future studies.

Egusa, S., and T. Yamamoto.

1961. Studies on the respiration of the "Kuruma" prawn *Penaeus japonicus* Bate—I. Burrowing behaviour with special reference to its relation to environmental oxygen concentration. Bull. Jpn. Soc. Sci. Fish. 27:22-27.

Describes changes in the burrowing behavior of the "Kuruma" prawn with respect to changes in dissolved oxygen concentration.

Flowers, C. W., W. T. Miller, and J. D. Gann.

1975. Water chemistry. Vol. II. *In* J. G. Gosselink, R. H. Miller, M. Hood, and L. M. Bahr (editors), Environmental assessment of a Louisiana offshore oil port and appertinent pipeline and storage facility, Vol. II, Append. V. 1, 86 p. Final report to Louisiana Offshore Oil Port, New Orleans, LA.

Water chemistry was evaluated in the vicinity of a proposed single-point mooring terminal and offshore oil pipeline. Temperature, pH, salinity, BOD-COD, organic matter, inorganic nutrients, and selected heavy metal data were collected monthly during 1973 and 1974. Temporal variations of these data and a large anoxic area discovered during the study were described. Numerous raw data are available in this report.

Foote, K.

1982. Observations of oxygen depletion in Louisiana offshore waters. Proc. 3rd Annu. Gulf Mex. Inf. Transfer Meeting, p. 185-186. U.S. Dep. Inter., Minerals and Management Serv., New Orleans, LA.

Summarizes the occurrence of hypoxia off Louisiana from 1978 to 1982. Describes the relationship of hypoxia with catches of demersal fish, plankton, and epibenthos. Provides a correlation of environmental parameters with hypoxia.

Fotheringham, N., and G. H. Weissberg.

1979. Some causes, consequences and potential environmental impacts of oxygen depletion in the northern Gulf of Mexico. Proc. 11th Annu. Offshore Tech. Conf. 4(3611): 2205-2208.

Factors affecting the formation of hypoxic bottom water and the assessment of major impacts of oxygen depletion in Louisiana nearshore waters are discussed. Water temperature, salinity, current velocity, and water chemistry are mentioned. Temporal changes in density and vitality of macrofauna with respect to the presence of oxygen-depleted water are noted.

Gallaway, B. J.

1981. An ecosystem analysis of oil and gas development on the Texas-Louisiana continental shelf. U.S. Fish Wildl. Serv., Office Biol. Serv., Wash., DC, FWS/OBS-81-27, 88 p.

Considered an overview of the Texas-Louisiana shelf ecosystem. Water currents, salinity, turbidity, dissolved oxygen concentration, bottom topography, and sediments are discussed. Zoogeographic faunal assemblages are presented and temporal variations are discussed. The effects of drilling structures, fluids, and oil spills on the above biological and physical data were investigated.

1982. Defining and obtaining management information related to oxygen depletion. Proc. 3rd Annu. Gulf Mex. Inf. Transfer Meeting, p. 190-193. U.S. Dep. Inter., Minerals and Management Serv., New Orleans, LA.

Presents historical data associated with changes in Mississippi River waters, summarizes reports of hypoxia and major biological changes in Gulf water, and suggests the development of assimilative models for the Texas-Louisiana shelf ecosystem.

Gallaway, B. J., and L. A. Reitsema.

1981. Shrimp spawning site survey. Vol. III. *In* W. B. Jackson and E. P. Wilkens (editors), Shrimp and redfish studies; Bryan Mound brine disposal site off Freeport, Texas, 1979-1981. NOAA Tech. Memo. NMFS-SEFC-67, 84 p. Natl. Tech. Inf. Serv., Springfield, VA.

Reports on the impact of brine disposal from the Bryan Mound disposal site off Texas. Data were collected at one offshore and two nearshore sites in order to determine the presence and magnitude of brown and white shrimp spawning. Hydrographic data (including dissolved oxygen concentration), sediment TOC and grain size, meristic notes on fish and shrimp catch, biochemical analyses of benthic infauna, and histological information on various shrimp tissues were gathered.

Garlo, E. V., C. B. Milstein, and A. E. Jahn.

1979. Impact of hypoxic conditions in the vicinity of Little Egg Inlet, New Jersey in summer 1976. Estuarine Coastal Mar. Sci. 8:421-432.

A mass mortality of marine organisms in the presence of hypoxic bottom water is described. Benthic infauna and epifauna, fouling organisms, and fishes were affected. Abnormal seasonal variation of several environmental parameters is discussed with respect to the formation of hypoxic bottom water.

Gosselink, J. G., R. R. Miller, M. Hood, and L. M. Bahr (editors).
1975. Environmental assessment of a Louisiana offshore oil port and appertinent pipeline and storage facility. Volume II. Tech. Append., 540 p. Final report to Louisiana Offshore Oil Port, New Orleans, LA.

A description of marine chemistry and biology in the vicinity of a proposed offshore pipeline and mooring terminal. Plankton, demersal nekton, benthos, avifauna, mammal, sediment, and hydrological data were recorded in and around the study area. Hypoxia documented during this study was the most widespread and severe in present day records.

Gunter, G.
1942. Offatts Bayou, a locality with recurrent summer mortality of marine organisms. Am. Midl. Nat. 28:631-633.

Fish and invertebrate kills in Offatts Bayou, from 1936 to 1941, are described. Dredging, the presence of hydrogen sulfide, oxygen depletion, salinity, water column stratification, and minimal tidal exchange with Offatts Bayou and West Galveston Bay are discussed in relationship to the mass mortalities.

Hagerman, L., and R. F. Uglow.
1982. Effects of hypoxia on osmotic and ionic regulation in the brown shrimp *Crangon crangon* (L.) from brackish water. J. Exp. Mar. Biol. Ecol. 63:93-104.

Monitors haemolymph chloride, magnesium, and calcium ions at various salinities (10, 15, and $20^0/_{00}$) and oxygen levels (PO_2 = 10-60 mm Hg). Discusses avoidance behavior of *C. crangon* to hypoxic water and chemical changes in its blood chemistry under hypoxic conditions which may increase the animal's ability to remove oxygen from water with a low PO_2.

Hann, R. W., and R. E. Randall (editors).
1982. Evaluation of brine disposal from the Bryan Mound site of the Strategic Petroleum Reserve Program. Final report of eighteen-month postdisposal studies. Vols. I and II, 1050 p. Prepared for the Department of Energy, Strategic Petroleum Reserve, Project Management Office, New Orleans, LA.

An indepth report containing information on various hydrological parameters, water and sediment quality, nekton, plankton, and benthos. Data were collected before, during, and after brine diffuser operation. Hypoxic bottom water was present in 1979.

Harper, D. E., Jr., L. D. McKinney, R. R. Salzer, and R. J. Case.
1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contrib. Mar. Sci. 24:53-79.

Reports on the first documented occurrence of widespread hypoxia in Texas waters. Variation in environmental parameters; species diversity; and species density before, during, and after the event is presented. Provides an understanding of the formation of hypoxic bottom water and contains a brief review of hypoxia in the Gulf of Mexico.

Harris, A. H., J. G. Ragan, and R. H. Kilgen.
1976. Oxygen depletion in coastal waters. Louisiana State University Sea Grant Summary Report, Proj. No. R/BOD-1, 161 p.

Discusses the formation of hypoxic water and its effect on commercial shrimp, fish, and other forms of marine life. Numerous environmental and biological data are provided. A baseline of normal environmental conditions versus hypoxic and anoxic conditions is presented.

Hochachka, P. W.
1980. Living without oxygen—Closed and open systems in hypoxia tolerance. Harvard University Press, Cambridge, MA, 181 p.

Presents biochemical aspects of anerobic metabolism in parasitic helminths, bivalve mollusks, cephalopods, fish, and diving mammals. Adaptations of organisms that normally live in an anoxic or hypoxic environment are discussed.

Imabayashi, H.
1983. Effects of oxygen-deficient water on the benthic communities. [In Jpn., Engl. abstr.] Bull. Jpn. Soc. Sci. Fish. 49:7-15.

Describes the effect of oxygen-depleted water on species composition, species diversity, and the number of individuals in a benthic community.

Ingham, M.
1982. Distress signals from inner space? Coastal Ocean. Climatol. News 4:47.

Provides a list of signs that suggest a worsening of environmental conditions is proceeding in the north central Gulf of Mexico. Discusses man-made versus natural causes of hypoxia using the New York Bight incident as an example.

Kramer, G. L.
1975. Studies on the lethal dissolved oxygen levels for young brown shrimp, *Penaeus aztecus* IVES. Proc. World Maricult. Soc. 6:157-167.

Brown shrimp tolerance to sudden salinity changes and varying rates of reduction of dissolved oxygen are described. Behavioral responses are recorded and analyzed with respect to shrimp size and sex. Avoidance of oxygen-depleted water by brown shrimp is hypothesized.

Landry, A. M., and H. W. Armstrong.
1980. Determine seasonal abundance, distribution and community composition of demersal finfishes and macrocrustaceans. Vol. IV. *In* W. B. Jackson and G. M. Faw (editors), Biological/chemical survey of Texoma and Capline sector salt dome brine disposal sites off Louisiana, 1978-1979. NOAA Tech. Memo. NMFS-SEFC-28, 180 p. Natl. Tech. Inf. Serv., Springfield, VA.

Provides seasonal variation in shrimp and finfish catch data, benthic community structure and sediment types at two study sites off Louisiana. Environmental data, including dissolved oxygen concentration, are presented.

Leming, T.
1983. Remote sensing discovers coastal water hypoxia in the Gulf of Mexico. Habitat perspectives, p. 11. Unpublished report by NOAA, NMFS, Office of Protected Species and Habitat Conservation, Wash., DC.

Brief summary of the role of satellite sensing with regard to discovering hypoxic water off Louisiana in 1982.

Loesch, H.
1960. Sporadic mass shoreward migrations of demersal fish and crustaceans in Mobile Bay, Alabama. Ecology 41:292-298.

Discusses the anomalous crowding of fish and invertebrates into the shallow waters of Mobile Bay, i.e., "jubilees." The recorded history of "jubilees" is presented. Temperature, salinity, and dissolved oxygen data are examined. Climatological data are also reported.

May, E. B.
1973. Extensive oxygen depletion in Mobile Bay, Alabama. Limnol. Oceanogr. 18:353-366.

Widespread hypoxia is documented in Mobile Bay, AL, in 1971. Historical references of resultant "jubilees," the shoreward movement of demersal fish and crustaceans are discussed. Causes and effects of hypoxia are mentioned.

McLeese, D. W.
1956. Effects of temperature, salinity and oxygen on the survival of the American lobster. J. Fish. Res. Board Can. 13:247-272.

Survivorship in all possible combinations of salinity (20, 25, and 30 ppt), temperature (5°, 15°, and 25°C), and dissolved oxygen concentration (2.9, 4.3, and 6.4 mg/l) were tested on acclimated and nonacclimated lobsters. Size differences, molting stage, starved and fed lobsters were considered. Resistance times are also identified.

Milstein, C. B., E. V. Garlo, and A. E. Jahn.
1977. A major kill of marine organisms in the Middle Atlantic Bight during summer 1976. Ichthyol. Assoc. Bull. 16, 56 p.

Reports on anoxia in the Middle Atlantic Bight in 1976. Physical and chemical aspects of the water, demersal fish, and benthic invertebrates affected by the low oxygen levels are discussed. Similar data collected from 1972 and 1975 are compared with the 1976 findings. Plausible causes and consequences of the kill are presented. Some raw data are included. Finally, the chronological reporting of the hypoxic occurrence is provided.

National Marine Fisheries Service.
1977. Oxygen depletion and associated environmental disturbances in the Middle Atlantic Bight in 1976. Northeast Fish. Cent., Tech. Ser. Rep. 3, 483 p. Sandy Hook Laboratory, NJ.

Reports on a series of workshops covering hypoxia and its consequences in the New York Bight. Climatic, oceanographic, and biological data are presented.

Nichols, J. A.
1976. The effect of stable dissolved-oxygen stress on marine benthic invertebrate community diversity. Int. Rev. Gesamten Hydrobiol. 61:747-760.

Reviews hypotheses explaining the effects of oxygen stress on community diversity, species diversity, the number of species present, and their numerical composition. Special reference is made to marine invertebrate communities in a stable oxygen stress environment.

Oetking, P., R. Back, R. Watson, and C. Merks.
1974. Hydrography on the nearshore continental shelf of of south central Louisiana. Offshore Ecol. Invest., Final report to the Gulf Univ. Res. Consort., Houston, TX, 56 p.

Dissolved oxygen concentration, temperature, salinity, transmissivity, water mixing, and photosynthesis are among several hydrographic parameters recorded during this study. Seasonal trends and interrelationships are discussed. Numerous raw data are available.

Officer, C. B., R. B. Biggs, J. L. Taft, L. E. Cronin, M. A. Tyler, and W. R. Boynton.
1984. Chesapeake Bay anoxia: Origin, development, and significance. Science (Wash., DC) 223:22-27.

Reviews history of anoxia in Chesapeake Bay. Temporal enhancement during the past 30 yr was investigated. Typical onset of annual hypoxia is described. Ecological and economic impacts and the magnitude of these impacts are discussed. Although this paper does not refer directly to the Gulf of Mexico, its findings may parallel those in the Gulf in the near future.

Ogren, L., and J. Chess.
1969. A marine kill on New Jersey wrecks. Underwater Nat. 6(2):4-12.

Reports on a fish kill off New Jersey in the fall of 1968. A list of dead and moribund fish and invertebrates is provided. Environmental anomalies preceding the kill are discussed. Scant hydrographic data are available. Recolonization of a wreck after 8 mo is described.

O'Reilly, J.
1983. NEFC monitors low dissolved oxygen levels off New Jersey. Habitat perspectives, p. 10. Unpublished report by NOAA, NMFS, Office of Protected Species and Habitat Conservation, Wash., DC.

Brief summary on hypoxic water noted off the New Jersey coast in 1983, its effect on bottomfish and accumulation of organic detritus on the ocean floor.

Parker, R. H., A. L. Crowe, and L. S. Bohme.
1980. Describe living and dead benthic (marco-meio) communities. Vol. I. *In* W. B. Jackson and G. M. Faw (editors), Biological/chemical survey of Texoma and Capline sector salt dome brine disposal sites off Louisiana, 1978-1979. NOAA Tech. Memo. NMFS-SEFC-25, 103 p. Natl. Tech. Inf. Serv., Springfield, VA.

A baseline survey of the benthic communities near two proposed brine diffuser sites. Geographic and temporal variation in community structure is described. A large anoxic region in the Gulf of Mexico is reported.

Ragan, J. G.
1975. Benthic macroinvertebrates. Vol. II. *In* J. G. Gosselink, R. R. Miller, M. Hood, and L. M. Bahr (editors), Environmental assessment of a Louisiana offshore oil port and appertinent pipeline and storage facility, Vol. II, Append. V. 5, 40 p. Final report to Louisiana Offshore Oil Port, New Orleans, LA.

Variability in the density of macroinvertebrates is discussed with respect to bottom depth, season, salinity, distance from shore, and bottom water dissolved oxygen concentration. Comparisons are made by species as well as with total number of species of invertebrates. Community composition and the number of organisms per species are presented.

Ragan, J. G., and A. H. Harris.
1975. Nekton. *In* J. G. Gosselink, R. R. Miller, M. Hood, and L. M. Bahr (editors), Environmental assessment of a Louisiana offshore oil port and appertinent pipeline and storage facility, Vol. II, Append. V. 6, 65 p. Final report to Louisiana Offshore Oil Port, New Orleans, LA.

A baseline study south of Belle Pass, LA, in a proposed area for an offshore oil pipeline. Provides estimates of relative abundance of fish and invertebrates and lists natural variation in species number and weight. Correlations between water quality and species diversity and abundance were determined. Temporal variation is included in these analyses.

Ragan, J. G., A. H. Harris, and J. H. Green.
1978. Temperature, salinity, and oxygen measurements of surface and bottom waters on the continental shelf off Louisiana during portions of 1975 and 1976. Nicholls State Univ. Prof. Pap. Ser. (Biol.) 3:1-29.

Ocean temperature, salinity, dissolved oxygen concentration, and monthly river discharge rates are presented. Seasonal analyses of these and additional data from 1973-74 are presented. Raw data are provided.

Ray, S. M.
1981. Areas of low dissolved oxygen, Gulf of Mexico. *In* P. Sheridan and S. Ray (editors), Report of the workshop on the ecological interactions between shrimp and bottomfishes, April, 1980. NOAA Tech. Memo. NMFS-SEFC-63, 132 p. Natl. Tech. Inf. Serv., Springfield, VA.

Synopsis of historical references to hypoxia on the inner continental shelf of the Gulf of Mexico and its apparent causes.

Reitsema, L. A.
1980. Determine seasonal abundance, distribution and composition of zooplankton. Vol. II. *In* W. B. Jackson and G. M. Faw (editors), Biological/chemical survey of Texoma and Capline sector salt dome brine disposal sites off Louisiana, 1978-1979. NOAA Tech. Memo. NMFS-SEFC-26, 133 p. Natl. Tech. Inf. Serv., Springfield, VA.

Temporal and geographic variation in zooplankton are discussed. Species diversity, species density, and dominant taxa are listed. Locations of hypoxic bottom water discovered during the study are noted.

Reitsema, L. A., B. J. Gallaway, and G. S. Lewbel.
1982. Shrimp spawning site survey Vol. IV. *In* W. B. Jackson (editor), Shrimp population studies: West Hackberry and Big Hill brine disposal sites off southwest Louisiana and upper Texas coasts, 1980-1982. NOAA/NMFS Final report to DOE, 88p. Natl. Tech. Inf. Serv., Springfield, VA.

Brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*, abundance and spawning activity off the upper Texas and Louisiana coasts were investigated at four inshore and three offshore regions. Notes on the occurrence of hypoxic bottom water during this study are included. Hydrographic data, substrate characterization, meristic notes on fish and shrimp catch, biochemical analyses of shrimp and benthic infauna, and histological information on various shrimp tissues were also gathered.

Renaud, M.
1983. Hypoxia returns to the Louisiana coastline. Habitat prespectives, p. 10. Unpublished report by NOAA, NMFS Office of Protected Species and Habitat Conservation, Wash., DC.

Brief summary of the hypoxic conditions off Louisiana in 1983. "Typical" sequence of events leading to the formation of hypoxia is described. An editing error in the last sentence of the second paragraph occurs. It should read "The offshore migrations of shrimp and fish may be affected by hypoxic bottom water."

Savage, N. B.
1976. Burrowing activity in *Mercenaria mercenaria* (L.) and *Spisula solidissima* (Dillwyn) as a function of temperature and dissolved oxygen. Mar. Behav. Physiol. 3:221-234.

Discusses the ability of the hard shell clam and the surf clam to burrow when exposed to extreme temperatures and low dissolved oxygen concentrations (<1.0 ppm). Habitat and geographic distribution of these clams are discussed with respect to temperature and oxygen tolerances.

Segar, D. A., and G. A. Berberian.
1976. Oxygen depletion in the New York Bight apex: Causes and consequences. *In* M. G. Gross (editor), Middle Atlantic continental shelf and the New York Bight, p. 220-239. Am. Soc. Limnol. Oceanogr. Spec. Symp. 2.

Oxygen and carbon dioxide cycles are examined. Major sources of oxygen demand are identified. The history of low dissolved oxygen in the New York Bight is reviewed. Primary production and nutrient sources are considered. The consequences of discontinuing sewage and spoil dumping are hypothesized.

Seki, H., T. Tsuji, and A. Hattori.
1974. Effect of zooplankton grazing on the formation of the anoxic layer in Tokyo Bay. Estuarine Coastal Mar. Sci. 2:145-151.

The effect of fecal pellet production by herbivorous copepods on the onset of anoxia is discussed. The relationship between phytoplankton density and the formation of phytodetritrus and fecal pellets is analyzed.

Sharp, J. H.
1976. Anoxia on the Middle Atlantic Shelf during the summer of 1976. University of Delaware, Lewes, 122 p.

A compilation of information on the extensive faunal mortality off Long Island, NY, in 1976. Topics include a general summary, meteorological data, phytoplankton distribution and production, modeling, an analysis of time-dependent factors possibly leading to anoxia, and the physical and biological characteristics of the region.

Shepard, M. P.
1955. Resistance and tolerance of young speckled trout (*Salvelinus fontinalis*) to oxygen lack, with special reference to oxygen acclimation. J. Fish. Res. Board Can. 12: 387-446.

The tolerance of juvenile speckled trout to oxygen-depleted water was determined. Avoidance behavior, resistance time, and acclimation times were investigated. An empirical method for describing the ability of fish to withstand hypoxia is presented.

Shick, J. M.
1976. Physiological and behavioral responses to hypoxia and hydrogen sulfide in the infaunal asteroid *Ctenodiscus crispatus*. Mar. Biol. (Berl.) 37:279-289.

Resistance of the starfish, *Ctenodiscus crispatus*, to hypoxia is noted. The compounding effect of hydrogen sulfide in the presence of hypoxia is discussed. Behavioral responses, including morphological changes, to hypoxia are examined.

Stuntz, W. E., N. Sanders, T. D. Leming, K. N. Baxter, and R. M. Barazotto.
1982. Area of hypoxic bottom water found in northern Gulf of Mexico. Coastal Oceanogr. Climatol. News 4:37-38.

Reports on hypoxic bottom water in the Mississippi River Delta Bight, in 1982, and the shrimp and fish associated with these areas. Remote satellite sensing of hypoxia is also discussed.

Swanson, R. L., and C. J. Sindermann (editors).
1979. Oxygen depletion and associated benthic mortalities in New York Bight, 1976. NOAA Prof. Pap. 11, 345 p. Rockville, MD.

An indepth review of bottom water hypoxia and its effects on the commercial fisheries of the New York Bight in 1976. A compilation of papers covering physical characteristics, atmospheric conditions, chemical factors, bottom dissolved oxygen concentrations, water column stratification, water and oxygen transport, plankton dynamics, and biological processes before, during, and after the onset of hypoxia. The socioeconomic impacts and a perspective on natural and human factors are also presented.

Theede, H.
1973. Comparative studies on the influence of oxygen deficiency and hydrogen sulphide on marine bottom invertebrates. Neth. J. Sea Res. 7:244-252.

Survivorship of several marine benthic invertebrates, from the North and Baltic Seas, was measured in oxygen-deficient (<0.2 ppm) water. The additive effects of hydrogen sulfide, pH, salinity, and temperature were also considered. Tissue samples from these organisms were also

tested in a similar manner. In addition, the oxygen consumption of invertebrates at different oxygen tensions was measured.

Theede, H., A. Ponat, K. Hiroki, and C. Schlieper.
1969. Studies on the resistance of marine bottom invertebrates to oxygen deficiency and hydrogen sulphide. Mar. Biol. (Berl.) 2:325-337.

Survivorship of 14 marine benthic invertebrates, from the North and Baltic Seas, was measured in oxygen-deficient (<0.2 ppm) water. The additive effects of hydrogen sulfide, pH, salinity, and temperature were also considered. Tissue samples from these organisms were also tested in a similar manner.

Turner, R. E., and R. L. Allen.
1982. Bottom water oxygen concentration in the Mississippi River Delta Bight. Contrib. Mar. Sci. 25:161-172.

Describes geographic and seasonal variation of bottom water dissolved oxygen concentrations from south of Mobile Bay, AL, to south of Atchafalaya Bay, LA, from 1975 to 1980. Historic references to hypoxic water masses in the Gulf of Mexico are provided.

1982. Plankton respiration rates in the bottom waters of the Mississippi River Delta Bight. Contrib. Mar. Sci. 25: 173-179.

Discusses community plankton respiration (CPR) rates and oxygen depletion times in bottom waters of the Mississippi River Delta Bight during July and November 1976. Describes the relationship of CPR with suspended sediments, chlorophyll concentrations, and bottom water dissolved oxygen concentrations.

Vetter, R. D., and R. E. Hodson.
1982. Use of adenylate concentrations and adenylate energy charge as indicators of hypoxic stress in estuarine fish. Can. J. Fish. Aquat. Sci. 39:535-541.

Investigates the effect of hypoxic conditions on estuarine fish. Concentrations of ATP and total adenylates in white muscle are used as indicators of environmental stress.

Voyer, R. A., and R. J. Hennekey.
1972. Effects of dissolved oxygen on two life stages of the mummichog. Prog. Fish-Cult. 34:222-225.

Dissolved oxygen tolerance limits and percent mortality of adult and embryonic mummichogs are compared and contrasted. Hatching rates at various dissolved oxygen levels are discussed. The tolerance of juvenile menhaden, Atlantic silversides, and embryonic oysters to low oxygen concentrations is also mentioned.

Waddell, E., and P. Hamilton.
1981. Physical oceanography. Vol. I. *In* C. E. Comiskey and T. A. Farmer (editors), Characterization of baseline oceanography for the Texoma region brine disposal sites. Prepared for DOE, Strategic Petroleum Reserve Office, Wash., DC, 130 p.

Monthly water temperature, salinity, dissolved oxygen concentration, and current speed and direction were among several physical data collected near the proposed Texoma brine disposal site from 1977 and 1978. Factors controlling nearshore currents, water column stratification, and sediment TOC and grain size are discussed. Plankton, demersal nekton, and benthos were characterized for each site. Geographic and seasonal variation in the data are presented.

Ward, C. H., M. E. Bender, and D. J. Reish (editors).
1979. The offshore ecology investigation. Effects of oil drilling and production in a coastal environment. Rice Univ. Stud. 65(4-5), 589 p.

A compilation of papers on the physical and biological oceanography of Timbalier Bay and the offshore waters of Louisiana. Seasonal variation in the hydrographic parameters, sediment characters, fish and benthos community composition, and nutrient concentrations are described. The effects of oil production platforms on the above are considered.

Whitmore, C. M., C. E. Warren, and P. Duodoroff.
1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Am. Fish. Soc. 89:17-26.

Avoidance of oxygen depleted water (1.5-6.0 ppm dissolved oxygen concentration) by juvenile coho salmon, bluegills, largemouth bass, and chinook salmon is discussed. Seasonal variation in their responses is noted.

Wiebe, P. H.
1982. Rings of the Gulf Stream. Sci. Am. 246(3):60-70.

Examines the formation and separation of eddy currents from the Gulf Stream. Changes in physical and biological properties of these rings are discussed. Their role in the formation of regions of hypoxic water masses is hypothesized.

Wiseman, W. J.
1983. Physical processes which may impact the oxygen depletion zone over the Louisiana shelf. Proc. 3rd Annu. Gulf Mex. Inf. Transfer Meeting, p. 18-189. U.S. Dep. Inter., Mineral and Management Serv., New Orleans, LA.

Mississippi River flow into the Gulf of Mexico, water column stratification, and the intrusion of high salinity water from offshore are discussed with respect to the

formation of hypoxic bottom water in the Mississippi River Bight.

Young, J. S.
1973. A marine kill in New Jersey coastal waters. Mar. Pollut. Bull. 4:70.

Mortality of the American lobster, *Homarus americanus*, on ship wrecks off the New Jersey coast is discussed. Oxygen depletion is considered as a possible cause of mortality. Minimal data are available.

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